European Symposium on Computer Aided Process Engineering – 15
L. Puigjaner and A. Espuña (Editors)

Event-based Approach for Supply Chain Fault Analysis

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Abstract

This work is a contribution to fault propagation analysis in a supply chain network. An event-based fault detection method is applied to fault propagation analysis validation. The goal of this methodology is to discover and validate fault propagation effects on system variables. This knowledge could be used to improve corrective action design in order to compensate negative effects. The methodology has been applied to supply chain fault propagation analysis over inventory data. Once validated, fault propagation effects on inventory level could be compensated by adapting the inventory control policy. Thus, unnecessary inventory holding could be reduced.

Keywords: supply chain management, discrete event system, fault detection, process monitoring, fault propagation analysis

1. Introduction

Supply chain productivity and economic benefit strongly depend on the correct behaviour of each unit or activity involved. A raw material supply transport interruption or a production machine breakdown in a manufacturing plant can bring the supply chain to a decrease in efficiency, leading to unexpected economic costs. These undesired situations can be regarded as supply chain faults or incidents.

Due to the interconnected nature of supply chains, fault effects usually propagate through the system, degrading, as time goes on, the overall performance. After a production machine breakdown, a manufacturing plant will lately service orders posted by a distributor. Consequently, the distributor could also be forced to delaying orders posted by its costumers, and so on.

Anticipating the fault propagation effects could be beneficial in reducing the overall economic loses. Global corrective actions could be designed and planned beforehand off-line. As soon as a fault occurs, these corrective actions could be applied, compensating for fault propagation effects and thus minimizing economic loses.

In the machine breakdown example, the manufacturing plant would decide to repair the damaged machine, whereas at the same time the distributor would decide to

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immediately post its pending orders to another manufacturing plant while production is re-established in the former. This should be preferable to just waiting for repair.

In the literature, the analysis to determine how certain fault effects propagate through a system is known as fault propagation analysis. Blanke et al. (2003) propose a methodology for fault propagation analysis based on structural analysis, a technique which analyses the structural properties of mathematical models. However, whenever models are not available, their approach is not applicable.

The approach proposed in this paper is based on the observation of system signals. Faults modify the normal behaviour of system signals. Discovering temporal patterns originated by faults on these signals should help in anticipating negative fault effects.

Candidate fault propagation patterns could be generated by applying well-known data mining techniques as time series pattern recognition (Berndt et al., 1996) or clustering methods (Piera et al., 1991). These techniques allow for knowledge discovery. However, the observation of system signals by an expert could be enough to produce a candidate fault propagation pattern.

In this paper, candidates are generated from the observation of inventory levels. Inventory data is commonly registered by companies, so it will probably always be available for analysis. A methodology has been developed that allows for checking the correlation of a fault occurrence with a candidate fault propagation pattern.

This validation methodology is based on a process monitoring technique which has been previously applied to other domains such as biotechnological process supervision (Sarrate et al.,1998) or tool machine monitoring (Aguilar et al., 2001). In this work, its application has been extended and adapted to supply chain fault detection.

In Section 2, a brief description of the process monitoring technique applied to fault detection is presented. Guidelines to apply this technique to fault propagation analysis validation are given at the end of this section. Section 3 is devoted to illustrate the methodology on a supply chain network. Two fault scenarios are studied and results are discussed. Some concluding remarks on this methodology are given in Section 4.

2. The Fault Analysis Methodology

2.1 Event-based fault detection

Fault detection aims at determining faults present in a system and the time when they have occurred. A lot of research has been done in this field (Isermann, 1997).

In Sarrate (2002) a methodology for process monitoring is proposed and applied to tool machine fault detection. This fault detection methodology is organized in to stages: the *Interface* and the *Supervisor*.

2.1.1. The Interface

The *Interface* analyses system signals following the sliding window paradigm, in order to detect relevant events. Under this approach, data is processed in sets comprising a time window. A window slides over time, and is periodically sampled. For each sample, all window data is analyzed in order to produce a window attribute which constitutes new data. Output data produced by this sliding window mechanism could be analysed again following the same procedure. Applying this algorithm recursively with different kinds of analysis, the required significant information can be abstracted. For instance, signal trends can be generated by first applying a linear regression window-based analysis to obtain the slope. Next, the slope is classified over a set of intervals applying a statistical window-based analysis to obtain the mode, which represents the most probable signal trend.

Interface configuration is needed to adjust window parameters. Expert system knowledge is applied for *Interface* design and configuration.

2.1.2. The Supervisor

The *Supervisor* is build upon an automaton which models the system behaviour. It must describe normal operation as well as all faulty situations that should be able to detect. Expert system knowledge is needed to discover which event sequences are associated to faulty situations. In the automaton, states model system states whereas transitions are associated to events.

2.2 Fault propagation analysis validation

The Supervisor automaton models system behaviour as event sequences. Events are associated to relevant signal dynamics. Thus, the observation of a sequence of relevant signal dynamics allows a faulty situation to be detected. In fact, the automaton stores the fault propagation knowledge.

Fault propagation effects are often clearly visible on system variables. Thus, the observation of signals by a system expert should provide temporal patterns that a fault originates on them. Once this information is available, the automaton can be built.

Since fault detection methodology is based on fault propagation knowledge, the fault detection procedure can be used for fault propagation validation as follows:

1. A set of design signals must be available. These must correspond to normal as well as faulty behaviour. The design set could be generated by a simulation model or obtained by measurements in the real system.
2. Through expert observation of the design set, the fault detection system must be designed and configured:
    a. Relevant signals dynamics are to be identified. The *Interface* must be designed accordingly, so that it is able to detect these significant events.
    b. Fault propagation patterns are to be discovered. The automaton must be build, so that it models these patterns.
3. A set of validation signals must be available. The same considerations given for the design set apply.
4. The fault detection system is run on the validation set. A fault detection success validates the fault propagation knowledge. However, wrong fault detection performance indicates that the fault propagation knowledge was badly inferred.

3. Application to Supply Chain Fault Propagation Analysis

3.1. Problem statement

The fault analysis methodology will be applied to a supply chain. The model interconnects 6 entities, as illustrated in Figure 1.

Two types of flows are present. On the one hand, there is a material flow (raw material P and finished products A and B) from the supplier to costumers. On the other hand, there is an information flow (order) from costumers to the supplier.

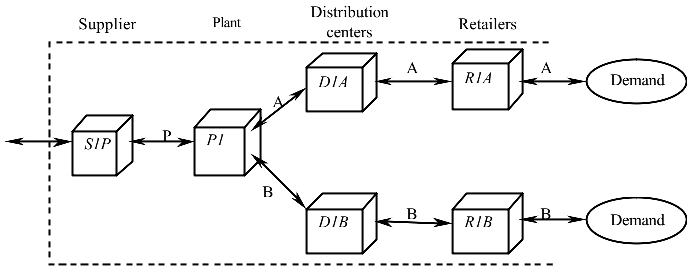

Figure 1. Supply chain network

Demand pattern has been simulated following a certain distribution probability.
Given the discrete event nature of the supply chain, its model has been simulated in *Matlab* using *Simulink* and *Stateflow* tools.
Two faulty scenarios were studied applying the fault analysis methodology developed in section 2:

- *Scenario 1*: A transient transport interruption of product B from P1 to D1B.
- *Scenario 2*: A transient production delay of product A.

The goal is to discover how these events have an effect on the inventory levels of the supply chain entities. Excess inventory incurs unnecessary holding costs, while the inability to meet the costumers needs results in both loss of profit and potentially, the long term loss of costumers.
The fault propagation knowledge can be used to design adequate corrective actions. For instance, once a fault has occurred and has been noticed, fault effects could be compensated adapting inventory control policies.

3.2. Results

Three design simulations were provided for the fault propagation analysis: the fault-free case, a transport interruption at 4000 s.u. for 65 s.u. and a production delay at 5000 s.u. during 700 s.u., where s.u. stands for simulation units (1 s.u. = 5 min.).
Figure 2 shows the inventory levels for some relevant supply chain entities under fault-free as well as faulty conditions. Apparently, the effects that both faults have on them can be easily appreciated. Both result in a transient increase of inventory levels for different supply chain entities.
The transport interruption significantly affects D1B inventory level, whereas the production delay slightly modifies D1B and D1A inventory levels.
In order to validate these fault propagation statements, the fault propagation analysis validation methodology has been followed.
For *Scenario 1*, the fault detection system illustrated in Figure 3 was designed a tuned. The trend detector implements the *Interface*. Significant trend events sequences are characterized in the *Supervisor* by a *Stateflow* automaton.
Fault detection results for the design set are illustrated in Figure 4. The first plot corresponds to the D1B inventory data. It shows also the fault detection at 4160 s.u.. Trend events are detected following the sliding window paradigm, as illustrated in section 2.1.1. The second plot corresponds to slope data obtained through a linear regression window-based analysis. And the third plot corresponds to the mode obtained from a statistical window-based analysis.

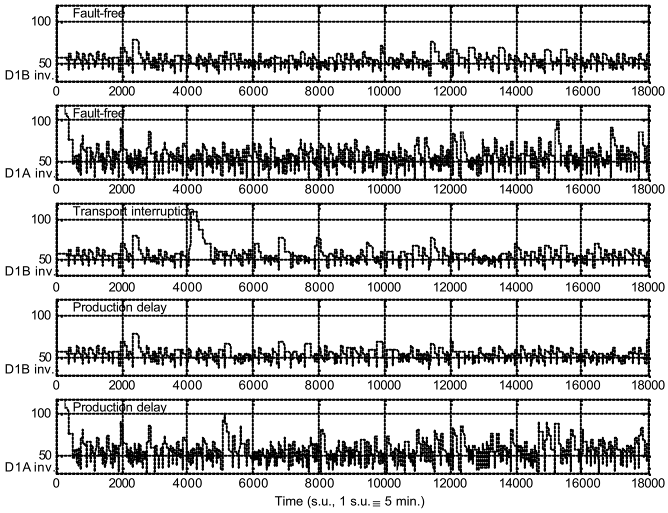

Figure 2. Design set

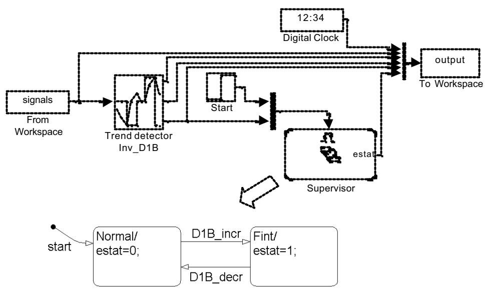

Figure 3. Event-based fault detection system and automaton for Scenario 1

Once designed and tuned, the fault detection system was used as a validation tool. A validation set was generated via simulation, varying fault time and duration. Table 1 summarises the validation results.

As expected, the longer the fault, the better the fault detection: over 250 s.u duration success is granted. This confirms the influence of this fault on the D1B inventory level.

For *Scenario 2*, a similar study was developed. Another fault detection system was designed but validation results were not so satisfactory. This confirmed the slight influence of this fault on supply chain entities. In this case, fault propagation effects were not generic applicable.

4. Conclusions

This work describes a methodology for fault propagation analysis and validation. Fault detection systems are designed for validation purposes. They are built from expert system knowledge, so no mathematical system descriptions or models are needed. As this fault detection system is built from fault propagation knowledge, it can be used for fault propagation validation.

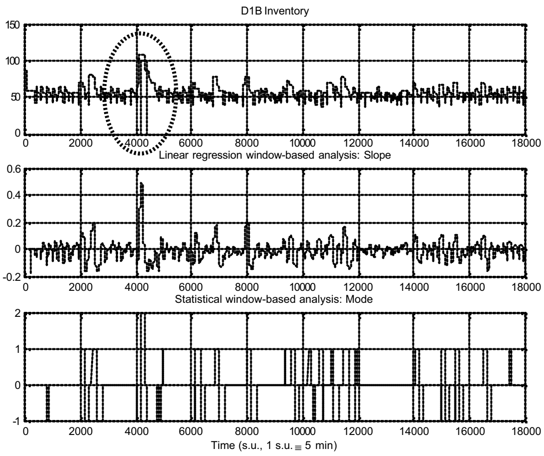

Figure 4. Event-based fault detection results for Scenario1 design set

Table 1. Validation results for Scenario 1 (X: wrong, √: success)

	Fault time (x10^3 s.u.)											
Fault duration (s.u.)	3	4	5	6	7	8	9	10	11	12	13	14
65	X	√	X	X	X	X	X	X	X	X	X	X
100	X	√	X	√	√	√	X	X	X	X	√	X
150	√	√	X	√	√	√	X	X	√	X	√	X
200	√	√	√	√	√	√	X	X	√	X	√	√
250	√	√	√	√	√	√	√	√	√	√	√	√

An application to supply chain fault analysis has been done. Results demonstrate the usefulness of this approach. Once fault propagation analysis is validated, adequate corrective actions could be planned to compensate for fault effects.

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